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Does the Development of Digital Finance Contribute to Haze Pollution Control? Evidence from China

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Abstract: Mitigating haze pollution is of practical significance to the green economy, and the development of digital finance may help achieve this goal. However, the effect of digital finance on haze pollution has not been systematically explained. Based on Chinese prefectural panel data for the 2011–2016 period, this study on haze concentration, technological innovation, and digital inclusive finance index as the dependent variable, mediating variable, and the core independent variable, respectively, investigated whether digital finance has improved haze pollution control in China using fixed effect (FE) and random effect (RE) models, a mediating effect model, a threshold panel model, and a dynamic spatial Durbin model (SDM). Four key results were obtained. (1) Digital finance significantly decreased haze pollution. After accounting for potential endogeneity, this conclusion was still valid. (2) The analysis of the influencing mechanism showed that digital finance was conducive to haze reduction by promoting regional innovation capabilities. (3) There was a nonlinear relationship between the influence of digital finance and haze pollution. Specifically, the impact of digital finance on haze pollution has gradually increased with the improvement of regional innovation capabilities. (4) Haze pollution displayed a significant positive spatial agglomeration in China. Digital finance can alleviate local haze pollution but will aggravate haze pollution in adjacent areas. Based on the results of this study, some pertinent policy suggestions were proposed.

Keywords: digital finance; haze pollution; mediating effect; nonlinear effect; spatial spillover effect

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1. Introduction

The widespread application of information and communication technology (ICT) has exerted a far-reaching influence on contemporary society and economic development [1]. The new digital information revolution has triggered a series of production and organizational changes [2], which has promoted human society to gradually move forward to the digital era [3]. China's digital economy, especially digital finance, has also boomed with the trend toward a global information process. The size of the digital economy in China increased from 22.4 trillion CNY 2016 to 35.8 trillion CNY 2019, with a growth rate of 16.5%, much higher than that of the gross domestic product (GDP). Although China's rapid construction of a digital finance system has stimulated economic progress and improved living convenience [4,5], too much attention has been given to the improvement of digital finance "quantity" at the expense of the development of "quality." With the extensive application of digital finance systems in China, problems such as resource depletion, air pollution, and ecological imbalance have become increasingly serious. Particularly since 2013, $PM_{2.5}$ has been the dominant air pollutant in China [6]. According to the statistics of China's Eco-environmental Status Bulletin in 2018, of 338 prefecture-level cities whose environment was monitored, 271 (64.2%) exceeded the Chinese ambient air quality standard of 35 $\mu g/m^3$, which is already far higher than the international air quality standard (10 $\mu g/m^3$) formulated by the World Health Organization (WHO) [7]. Thus, there is an urgent need to mitigate haze pollution. Recently, the Ministry of Ecology and Environment of China made a commitment to decrease the annual average $PM_{2.5}$ concentration of all cities to below the ambient air standard by 2030 [8]. Because of increasingly serious haze pollution and the vigorous progress of the digital process, the following practical questions need to be addressed. Does the application of digital finance improve haze pollution? If so, what is the internal mechanism by which it influences haze pollution? Specifically, we investigated the impact of digital finance on haze pollution from the perspectives of direct, indirect, non-linear, and spatial effects. Then we examined the mechanisms by which digital finance influences haze pollution.

The answers will provide marginal empirical support for optimizing the control of haze pollution through the application of digital finance. They will also provide examples for other countries in controlling and decreasing haze pollution. The research adopted a new perspective: we examined the impact of digital finance on haze pollution. It was found that digital finance contributes to reducing haze pollution through technological innovation. This study makes three specific contributions to the existing research in this area. (1) Against the background of digitization, we added digital finance to the research on haze pollution, which broadened the scope of the field regarding the environment and economy to a certain extent while discussing the mechanisms by which digital finance influences haze pollution. (2) This study investigated the impact of digital finance on haze pollution from the perspectives of direct, indirect, non-linear, and spatial effects by using fixed effect (FE) and random effect (RE) models, a mediating effect model, a threshold panel model, and a dynamic spatial Durbin model (SDM). (3) This study used instrumental variables and the synthetic difference in differences (SDID) method to alleviate potential endogenous problems and effectively assess the efficiency of administrative policy. This study provides policy support for digital finance to help reduce haze pollution, but also helps to realize the coordination between the development of digital finance and haze control, laying a foundation for the realization of sustainable economic development.

The rest of the paper is arranged as follows. Section 2 is a brief literature review that considers the focus of previous studies and identifies areas where there is a lack of research. Section 3 presents an analysis of the mechanism by which digital finance influences haze pollution and proposes the research hypothesis. Section 4 briefly explains the empirical methods and data used in this paper. Section 5 provides the empirical results and a discussion. Finally, Section 6 provides the conclusions and related policy implications.

2. Literature Review

Digital finance is a new generation of financial services that combines ICT with traditional financial services [9]. The nexus of digital finance and haze pollution can be studied by reviewing the previous literature regarding the relationship between ICT and haze pollution.

Many scholars at home and abroad have researched haze pollution and its influencing factors. Environmental regulation [10,11], foreign direct investment (FDI) [12,13], the energy consumption structure [14,15], environmental information disclosure [16,17], the fiscal and taxation system [18,19], economic growth [20,21], and technological innovation [16] were found to be significant factors affecting environmental quality. With the progress of digital information technology, many researchers have considered the impact of ICT on macroeconomic effects and air pollution. However, existing studies have mainly focused on the macroeconomic effects of ICT [22–25]. They indicated that the emergence of the Internet has significantly promoted economic development from a regional, national, and global perspective.

In addition, a small number of researchers have begun to study the impact of ICT on environmental pollution. However, because of their different research perspectives, objects, and methods, a consistent conclusion has not been drawn. Based on the final impact of ICT on environmental pollution, there are two mainstream perspectives regarding the relationship. The first is that ICT could exacerbate environmental pollution. This is because ICT is closely linked to our lifestyles and production activities, which include resource utilization and energy consumption [26], and the production of pollutants such as noxious gases and harmful garbage [27,28]. In an empirical environmental study, Steffen et al. (2020) [29] examined the impact of Internet use on the power demand in developing economies, and the results revealed that Internet use prominently increases electricity consumption resulting in serious environmental pollution. Since then, many scholars have confirmed this view. Based on this, Yang et al. [30] used the dynamic Durbin model to analyze the effect of Internet development on haze pollution and found that in the initial stage ICT aggravates environmental pollution while there is significant heterogeneity between direct and indirect spillover effects. In addition, ICT could exacerbate environmental pollution through a rebound effect [31], in which ICT can first improve energy efficiency but still increases energy consumption [32] and income [33]. For example, Lange et al. [29] found that, because of the income effect, the higher the level of ICT development, the higher the level of energy consumption. Other similar studies include Zhou et al. [34].

The other school of thought is that ICT can improve environmental quality by optimizing the production process, reducing energy consumption, and strengthening environmental management [35–39] Various researchers have conducted extensive empirical research to reach this conclusion. For example. Lin et al. [2] took Chinese provincial data from 2006 to 2017 as the research object and indicated that Internet development mainly improves energy and environmental quality by promoting industrial structure upgrading and technology diffusion. In addition, some scholars have verified the correctness of this view from the micro level. Wen et al. [40] investigated the relationship between industrial digitalization and enterprise environmental performance by employing a large sample of Chinese manufacturing enterprises; the result indicated that ICT improves environmental quality significantly. With the rapid development of ICT, some scholars have discussed the impact of related industries such as big data [41], mobile communication [42] and other information technology on the environment and reached similar conclusions.

Additionally, according to the Environmental Kuznets Curve (EKC), there is an inverted U-shaped relationship between environmental quality and economic development level. Many scholars have investigated whether this theorem is followed regarding the development of ICT and environmental pollution. Some studies have shown that there is a nonlinear relationship between the widespread utilization of ICT and environmental pollution. For instance, Halder et al. [43] investigated whether the EKC hypothesis existed for both Internet and mobile use and found that emerging economies have already reached the turning point of EKC, whereby increasing Internet penetration reduces CO_2 emission. Faisal [44] confirmed the existence of a U-shaped relationship between Internet use and electricity consumption in Turkey, and a similar study was conducted by Arshad et al. [45].

In summary, these studies have indicated that the question of environmental pollution has attracted extensive research attention. Although this research provided a strong background for this study, there were still deficiencies that could be improved on. The advancement of ICT infrastructure and services, particularly digital finance, is an important driver of economic growth that can affect environmental quality. However, there have been few studies on the possible links between digital finance and haze pollution. Previous studies have mainly focused on the direct effects of ICT on the environment, while ignoring the more important indirect effects of ICT (digital finance). Furthermore, the impact of digital finance on haze pollution is heterogenous across different regions and different periods. However, few studies have focused on the spatial effects and regional differences of ICT on haze pollution. In addition, the overall structure of the paper is shown in Figure 1.

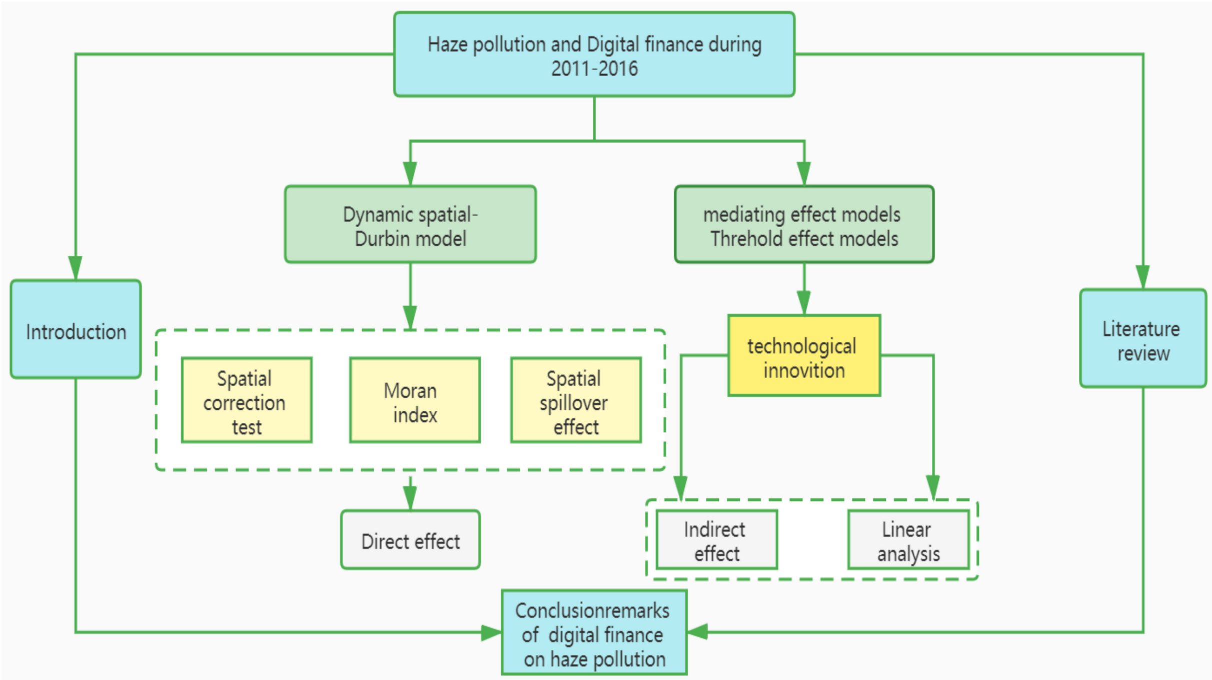

Figure 1. The research framework.

3. Mechanism Analysis

Unlike previous studies, this study considered the impact of digital finance on haze pollution from the perspective of indirect effects. It was found that digital finance reduces haze pollution through technological innovation. Refer to the mechanism analysis diagram in Figure 2. The mechanism by which digital finance influences haze pollution was analyzed as follows.

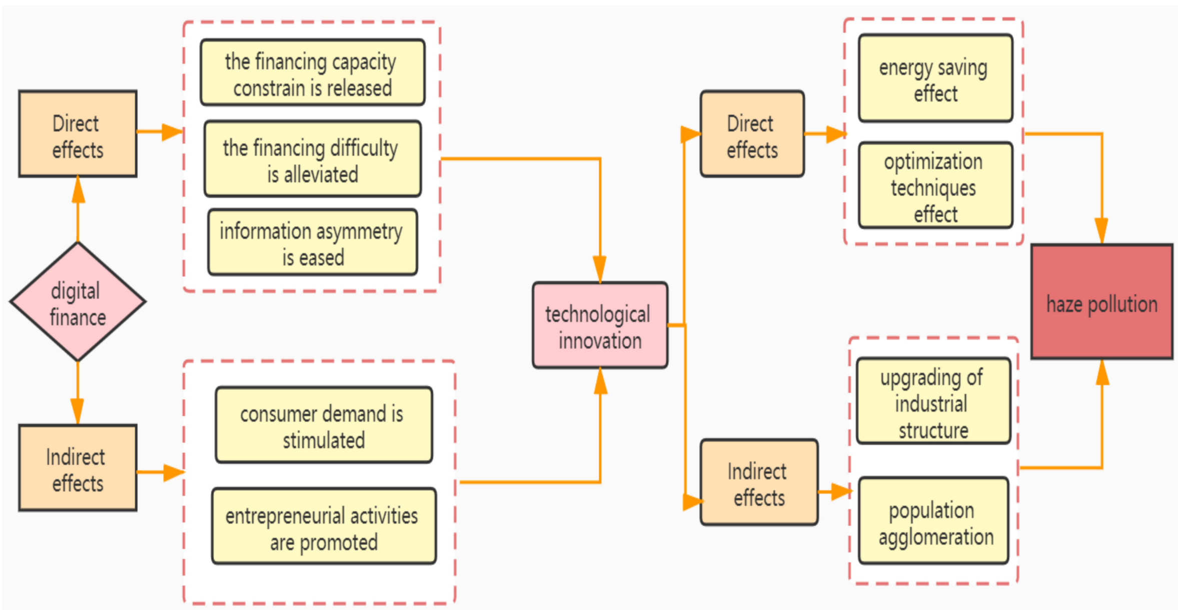

Figure 2. Analysis of the mechanism by which digital finance influences haze pollution.

There are both direct and indirect ways for digital finance to affect innovation activities. First, with the penetration of digital finance, the advantages and essential characteristics of the transtemporal information dissemination of digital finance [46] as well as the sharing and low cost of information acquisition have overcome the constraints of time and space, with the result that underdeveloped areas are no longer restricted [31,44]. This has alleviated the problem of the expensive financing and financing capacity constraints [43] for remote areas and small-to-medium-sized enterprises and enhanced the level of enterprise innovation. Second, as a resource allocation tool in a market economy, digital finance can allocate capital effectively, enabling the resource to gradually flow from low marginal benefit departments to high marginal benefit departments [47], which reduces the problem of information asymmetry between financial departments and companies [48]. Therefore, enterprises can invest more capital in innovation. In addition, digital finance has begun to indirectly affect innovation. Specifically, digital finance has facilitated payment transactions by urban residents using platforms such as WeChat and Alipay, which has altered the original consumer demand structure and satisfied the growing desire to consume [49]. This change in demand structure has generated a new production pressure on enterprises, accelerating their transformation and upgrading the traditional production mode, thereby forcing enterprises to accelerate innovation. The development of digital finance has also provided an important carrier of promoting entrepreneurial activities [50], which is conducive to the introduction of innovation [51].

Technological progress and innovation are the two significant variables in resource conservation and environmental protection [52,53]. Technical innovation activities can effectively improve the intelligence level of enterprise production equipment and the efficiency of the allocation of resources within an enterprise [54]. Based on this, low-energy production equipment can be replaced by high-energy production equipment, which reduces the resource input and energy consumption required for producing products. In addition, innovation activity can stimulate the upgrading of industrial structures by guiding the rational allocation of resources. Enterprises are forced to change the traditional mode of production and management models, and traditional but non-innovative industries are eliminated, thereby reducing environmental pollution. The change in industrial structure caused by innovation leads to a change in the resource market, which promotes the transfer of capital and labor to cities [55]. Although this will accelerate population agglomeration it will also improve resource utilization efficiency and therefore reduce pollution.

Based on above theoretical mechanism analysis, we propose Hypothesis 1 as follows:

Hypothesis 1. *Digital finance can reduce haze pollution through a technological innovation effect.*

4. Model Specification and Variable Description

4.1. STIRPAT Model

This study investigated the connection between digital finance and haze pollution. As baseline models, it used the two principal theoretical frameworks, the Environmental Kuznets Curve (EKC) and the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT), which are based on the foundation of Dietz and Rosa. The EKC was developed from the Kuznets curve, which uses the nonlinear association between economic development and inequality of income to explain the dynamics between economic development and degradation due to development.

The STIRPAT model is an extensible stochastic environmental impact assessment model. It constructs regression equations by taking population, property, and technology as explanatory variables to explain environmental pressure and better measure the impact of socioeconomic factors on the environment, which is often used as a basis for investigating the role of various factors that drive environmental pollution:

$$I_{it} = \alpha \times P_{it}^{b} \times A_{it}^{c} \times T_{it}^{d} \times e_{it} \quad (1)$$

where I represents environmental influence; P, A and T denote population size, wealth, and technological advancement, respectively. Based on the research framework of the EKC hypothesis, environmental issues cannot be separated from economic issues. Therefore, the basic framework is presented as:

$$I_{it} = a \times ifi_{it}^{b} \times gdp_{it}^{c} \times (gdp^2)_{it}^{d} \times e_{it} \quad (2)$$

where I_{it}, *ifi*, and *gdp* represent the haze pollution, digital finance, and economic levels, respectively, of city *i* for year *t*; *a* is a constant; *b*, *c* and *d* are the elastic coefficients; and e_{it} is a random disturbance term.

This paper used data for 284 Chinese cities and extended the STIRPAT model to incorporate the effects of digital finance and technological innovation to analyze the key factors behind haze pollution. According to previous studies, in addition to *ifi* and *gdp*, the upgrading of industrial structure is a key factor in energy-saving and eco-friendly production, environmental regulation has the most direct impact on haze pollution, while a dense population will generate a large number of pollutants. Foreign direct investment and fiscal expenditure affect haze pollution. Thus, the extended STIRPAT equation can be expressed as follows:

$$I_{it} = a \times \text{ifi}_{it}^{\alpha_1} \times gdp_{it}^{\alpha_2} \times (gdp^2)_{it}^{\alpha_3} \times gov_{it}^{\alpha_4} \times te_{it}^{\alpha_5} \times fdi_{it}^{\alpha_6} \times den_{it}^{\alpha_7} \times str_{it}^{\alpha_8} \times road_{it}^{\alpha_9} \times er_{it}^{\alpha_{10}} \times e_{it}. \quad (3)$$

To eliminate possible heteroscedasticity by taking the natural logarithm of variables, the refined STIRPAT decomposition model is as follows:

$$\begin{aligned} \ln I_{it} &= \ln a + \alpha_1 \ln ifi_{it} + \alpha_2 \ln gdp_{it} + \alpha_3 (gdp^2)_{it} + \alpha_4 gov_{it} + \alpha_5 fdi_{it} + \alpha_6 den_{it} + \alpha_7 str_{it} \\ &+ \alpha_8 road_{it} + \alpha_9 er_{it} + e_{it} \end{aligned} \quad (4)$$

where *ifi* is the core independent variable, digital finance; *gov*, *fdi*, *den* represent fiscal expenditure, foreign direct investment, and dense population, respectively. Meanwhile, *str*, road, and *er* denote the upgrading of industrial structure, transportation, and environmental regulation, respectively.

4.2. Mediating Effect Model

According to Hypothesis 1, digital finance may have an impact on haze pollution through technological innovation. The mediating effect model was applied to test the hypothesis in Equations (3)–(5):

$$\ln I_{it} = \ln a + \alpha_1 \ln ifi_{it} + \alpha_2 z_{it} + u_i + e_{it}, \quad (5)$$

$$Medit_{it} = \beta_0 + \beta_1 \ln ifi_{it} + \beta_c Z_{it} + u_i + e_{it}, \quad (6)$$

$$\ln pm_{it} = \gamma_0 + \gamma_1 \ln ifi_{it} + \gamma_2 medit_{it} + \gamma_3 z_{it} + u_i + e_{it} \quad (7)$$

where $Medit_{it}$ represents the mediating variable, i.e., technological innovation. $\propto_i, \beta_i, \gamma_i$ are the elastic coefficient, and the rest of the letters are the same as above. Formulas (5)–(7) together constitute the mediating effect model. Formula (5) calculates the impact of the development of digital finance on haze pollution; Formula (6) calculates the impact of the level of development of digital finance on the mediating variable; and Formula (7) calculates the impact of the development of digital finance and the mediating variable on haze pollution. When *a* in Formula (5) is significant, it indicates that the development of digital finance has a significant impact on haze pollution, and we then observe whether β_1 in Formula (6) and γ_2 in Formula (7) are significant. If β_1 and γ_2 are significant at the same time, they indicate that the development of digital finance will affect China's haze pollution through the mediating variable. If γ_1 is also significant, it means that the level of development of digital finance not only directly affects haze pollution but also affects haze pollution through the influence of the mediating variable.

4.3. Threshold Panel Model

To further test the nonlinear relationship between the development of digital finance and haze pollution, a threshold panel model was applied to conduct an empirical test of the nonlinear mechanism. This paper took the digital financial index and technological innovation as respective threshold variables. The advantage of this was to set digital financial index and innovation as piecewise functions to measure the impact of digital finance on haze pollution under different thresholds. The threshold panel model is as follows:

$$\ln pm_{it} = \alpha_0 + \varphi_1 \ln ifi_{it} \times I(adj_{it} \leq \vartheta) + \varphi_2 \ln IFI_{it} \times I(adj_{it} > \vartheta) + \varphi_c z_{it} + \mu_i + \varepsilon_{it} \quad (8)$$

where *adj* is the threshold variable, i.e., digital finance (ln*ifi*) technological innovation (ln*te*), ϑ is the threshold value to be estimated; and $I(.)$ is an instruction function.

4.4. Spatial Durbin Model (SDM)

Existing studies have mainly discussed the problem of haze pollution in a non-spatial framework while ignoring the spatial interaction. However, haze pollution has the characteristics of wide coverage, strong mobility, long hazard duration, and uneven spatial distribution. Therefore, the spatial econometric model was used to analyze the impact of digital finance on haze pollution. In addition, the SDM is a more comprehensive form of spatial lag model (SLM) or spatial error model (SEM), and in the process of spatial measurement, the SDM can also reflect the spatial correlations of dependent variables (i.e., direct and indirect effects). This enabled us to conduct a comprehensive analysis of the impact of digital finance on haze pollution. Therefore, we used the SDM to investigate the spatial spillover effect of haze pollution under the development of digital finance. Haze pollution may have a "time inertia" effect. We incorporated the spatial lag of haze pollution into the model. Based on the above theoretical analysis, the following dynamic SDM was constructed:

$$\begin{aligned} \ln pm_{it} = {} & \alpha_0 + \tau \ln pm_{i,t-1} + \eta \textstyle\sum_{i=1}^{n} w_{ij} \ln pm_{i,t-1} + \gamma \textstyle\sum_{i=1}^{n} w_{ij} \ln pm_{j,t} + \beta_1 \ln z_{it} + \\ & \beta_2 \textstyle\sum_{i=1}^{n} w_{ij} z_{jt} + u_i + \theta_{\mathrm{t}} + \varepsilon_{it} \end{aligned} \quad (9)$$

where γ, τ, and η are the spatial lag effect coefficient, the time lag effect coefficient, and the time-space double lag effect coefficient, respectively; α is a constant term, β is the parameter of z_{it}, θ is the spatial spillover effect coefficient of the explanatory variables, u_i is the individual fixed effect, w_{ij} is the spatial weight matrix, λ_i is the time fixed effect, and ε_{it} is the error term.

4.5. Explanation of Variables

4.5.1. The Dependent Variable

The dependent variable in the regression model was $pm_{2.5}$ concentration (lnpm). It is well-known that $PM_{2.5}$ is the fundamental class of particulate components responsible for haze pollution. The $pm_{2.5}$ concentration is therefore indicative of the severity of the impact of haze pollution. In relation to the processing methods of other scholars on haze data [56], this paper extracted $PM_{2.5}$ concentrations from 2011 to 2016 according to the annual $PM_{2.5}$.

Density map released by the Center for International Earth Science Information Network (CIESIN) using ArcGIS 10.0. The information obtained by satellites comprised non-point source data, capturing the changes in $pm_{2.5}$ concentrations, and reduced the data error.

4.5.2. The Core Independent Variable

The core independent variable in the regression model, digital finance, was compiled by Peking University, Shanghai Finance Institute, and Ant Financial Services by measuring the development level of digital finance [49]. The digital inclusive finance index covers a wide range of areas: province, municipality, and country. This research was based on digital finance data at the municipal level. In addition, the index includes three dimensions, including coverage breadth, depth of use, and digital support services, which are used for a robustness check.

4.5.3. The Mediating Variable

The mediating variable was technological innovation (*te*). The indicators were obtained from the FIND Report on City and Industrial Innovation in China (2017), which used econometric and statistical methods to comprehensively evaluate China's technological innovation capability and provided a "panorama of Chinese innovation" for government and research institutions. This study mainly used data at the municipal level for the regression analyses.

4.5.4. Control Variables

Because many factors can affect environmental pollution, a series of control variables were introduced. They included:

(1) Opening-up level (*lnfdi*). The actual amount of FDI in a year was used to show the level of opening-up. The impact of FDI on pollution is still inconclusive. On the one hand, the pollution halo hypothesis indicates that foreign investment has a technology spillover effect, which, to some degree, is instrumental in environmentally friendly production and the reduction of haze pollution [57] On the other hand, some studies have shown that FDI aggravates haze pollution. This is because some emerging countries lowered the entry threshold for foreign companies to introduce more foreign investment, making developing countries a "pollution paradise" [58]. Therefore, we could not determine the final impact of this variable on haze pollution.

(2) Transportation *(lnroad*). In previous studies, the impact of transportation was usually indicated by the per capita urban road area. However, this study took a prefecture-level city as the research object, as the available per capita urban road area data were seriously deficient. Cheng et al. (2020) [59] analyzed the passenger transportation volume, which to a certain extent can represent the impact of transportation. Therefore, the passenger transportation volume was used to represent transportation. When the passenger transportation volume increased significantly, more pollution was released. Thus, the expected direction of influence of this variable on haze pollution was negative.

(3) Economic growth (*lnpgdp*). The natural logarithm of GDP per capita was used as a measurement of the economic development level. There were two considerations to make regarding the impacts of GDP on pollution. On the one hand, when the economy is developing in the initial stage, the government pursues GDP quantity instead of stressing its quality. Enterprises as well aim to maximize revenue by expanding production scale, resulting in serous pollution [60]. On the other hand, with the steady improvement of the economy, the establishment of a large-scale economy and the enhancement of public requirements for environmental quality contribute to green economic development [61].

(4) Population density (*lnden*). Population density refers to the permanent resident population per km^2. Specifically, the increased concentration of population intensifies industrial agglomeration and encourages energy consumption, thus aggravating air pollution. On the other hand, the concentration of population may also improve the efficiency of energy utilization and resource recycling, which will decrease pollution emission. Therefore, it was uncertain whether this variable would promote or inhibit haze pollution.

(5) Industrial structure (*lnstr*). Industrial structure is a fundamental factor influencing air pollution and should be incorporated into the model when investigating the effect of digital finance on haze pollution. Referring to Lange et al. (2021) [62], the industrial structure was calculated based on the following equation:

$$str = \sum_{i=1}^{3} I_i \times i = I_1 + I_2 \times 2 + I_3 \times 3 \quad (10)$$

where I represents the proportional output of industry i, and the larger value of str is the higher degree of industrial structure.

(6) Environmental regulation level (*lner*). The environmental regulation index is a critical measure by which authority controls air pollution and needed to be adopted in this research. The higher the environmental regulation level, the stronger the environmental protection levels will be. The logarithm of industrial wastewater treatment was used to represent environmental regulation.

(7) Scale of government (*lngov*). A government with a large fiscal expenditure may have a sufficient budget to reduce haze pollution. Some studies have proved that with an increase in the size of government, environmental conditions improve [63]. we used the logarithm of government expenditure to express the size of government.

4.6. Data Description

An empirical study was conducted using the panel data of 284 prefecture-level cities in China from 2011 to 2016, as shown in Table 1. The time period and countries were selected based on the availability of data, especially for our critical variables of interest. Apart from $PM_{2.5}$ data, digital finance data, and technological innovation data, the relevant data for other variables were mainly obtained from the *China City Statistical Yearbook* and *China Energy Statistics Yearbook*. To ensure the scientific accuracy of the empirical analysis, the relevant raw data were technically processed. In addition, all the raw data were logarithmically normalized to eliminate the variable heteroscedasticity. Finally, small amounts of missing data were obtained by interpolation.

Table 1. The statistical description of variables.

Variable	Obs	Mean	S.D.	Min	Max
$lnpm$	1704	3.696	0.48	1.419	4.702
$lnifi$	1704	4.776	0.49	2.834	5.509
te	1704	13.59	57.411	0.005	1061.372
$lngdpp$	1704	10.599	0.583	8.773	13.056
$lngdpp2$	1704	112.681	12.443	76.964	170.451
$lnfdi$	1704	11.831	1.918	4.651	16.835
$lngov$	1704	14.723	0.721	12.031	18.052
$lnden$	1704	5.753	0.886	2.305	7.882
$lnstr$	1704	5.42	0.078	4.882	6.876
$lnroad$	1704	9.075	1.337	3.695	13.153
$lner$	1704	4.334	0.446	0.713	4.668

As can be seen in Table 1, haze pollution was relatively serious, with an average value of 3.696 from 2011 to 2016. In terms of core explanatory variables, in the sample period the average development level of digital finance was 4.776, and the variance was large, which indicated that there were significant differences in the development levels of different regions. For the intermediate variable *te*, the gap between cities was huge, and the variance reached 57.411. For the control variables, there were obvious differences in specific variables among cities. Among them, the gap between cities in per capita GDP was the largest, and the gap between cities in government expenditure level was small.

5. Empirical Results and Discussion

5.1. Baseline Regression Estimation Result

The empirical estimations began with the application of the *FE* and random effect (*RE*) models. The choice between *FE* and *RE* models was subject to a Hausman test. The null hypothesis of this test was that the *FE* was the appropriate model as a fixed effect (*FE*) model because it included individual effects and resulted in more accurate regression results. A panel threshold model was used to test for a nonlinear relationship between the development of digital finance and haze pollution. Finally, the spatial econometric model was used to analyze the impact of digital finance on haze pollution.

Table 2 shows the results of the baseline regression model. The digital finance and haze pollution relationship was examined beginning with Hypothesis 1. It indicated that regardless of whether the control variables were increased, an increase in digital finance had a significant (at the 1% level) negative effect on haze pollution, with coefficients of elasticity of −0.037 and −0.092, respectively, in both estimators (*FE* and *RE*). The fundamental reason for this result was that the widespread use of digital finance helps enterprises to improve their management and production innovation capability, which can enhance resource utilization efficiency and reduce haze pollution.

Table 2. Estimation results of the FE and RE methods.

Variables	(1) FE	(2) RE	(3) FE
$lnifi$	−0.037 *** (0.013)	−0.092 *** (0.012)	−0.197 *** (0.007)
$lngov$	−0.307 *** (0.030)	−0.182 *** (0.023)	
$lnfdi$	0.006 (0.005)	0.010 ** (0.005)	
$lnden$	−0.068 (0.109)	0.398 *** (0.022)	
$lngdpp$	−1.070 *** (0.293)	−1.085 *** (0.282)	
$lngdpp2$	0.045 *** (0.013)	0.045 *** (0.013)	
$lnstructure$	−0.054 (0.057)	−0.087 (0.058)	
$lnroad$	0.006 (0.009)	0.017 ** (0.008)	
$lner$	0.028 ** (0.012)	0.030 ** (0.012)	
Constant	15.143 *** (1.676)	11.032 *** (1.545)	4.635 *** (0.032)
R-squared	0.462	0.444	0.386
Fixed Effect	YES	NO	YES

Note: The prefix "ln" before the explanatory variables denotes a logarithmic form; ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. Figures in () are the t-value of the coefficients (these notes apply to the tables that follow).

Simultaneously, we analyzed the influence of other variables. The coefficient of *lnden* was negative but not significant (the elasticity coefficient was −0.068), signifying that population density had no remarkable impact. In urban areas, production and daily activity will likely raise energy consumption and pollution emissions, but environmental efficiency is also likely to improve with population agglomeration [60]. Thus, the influence of population density was unclear.

The early stages of economic growth helped to significantly reduce pollution, but later economic growth contributed to haze pollution with coefficients of elasticity of −1.07 and 0.045, respectively. This indicated the U-shaped relationship. Currently, an increase in GDP can significantly decrease haze pollution; this result was similar to the seminal work by Shahbaz et al. (2015) [52].

From the perspective of the scale of government, the elasticity coefficient was −0.307, and there was a significantly negative correlation with haze pollution. With an increase in fiscal expenditure, the government will be better able to focus on environmental governance. Hence, with the increase in environmental expenditure, haze pollution will eventually improve. The similar conclusion was reached by Zhang et al. (2021) [61].

The effect of FDI on haze pollution was not significant owing to the effects offsetting each other, with coefficients of elasticity of 0.006. Because of the pollution halo effect, the technology spillover effect, and the income effect, FDI will promote environmental improvement [13] Unfortunately, FDI can support high pollution enterprises that destroy the environment [59]. The interaction between positive and negative effects determined the significance of FDI. This result was similar to Walid (2021) [64].

The upgrading of industrial structure the impact coefficient was −0.054, which was not significant. This suggested that haze pollution was not obviously influenced by the upgrading of industrial structure. There were several possible reasons for this. China is in a period of transition from secondary to tertiary industry, and industrial upgrading and optimization have not yet been completed. Additionally, because of the lack of development of the service industry to high quality levels, tertiary industry has not yet had time to exert a mitigation effect on haze pollution.

The coefficient of environmental regulation was significantly positive, with coefficients of elasticity of 0.028. For long time, local governments in China have experienced fierce economic competition in the pursuit of economic prominence, with local governments attracting substantial investment instead of stressing quality. There has even been the emergence of "base-to-bottom competition" in environmental regulation [65], which has weakened the effectiveness of green technology. The coefficient of transportation was insignificantly positive, indicating that although automobile exhaust emissions are an important factor in haze pollution [6], improvements in transportation infrastructure will only partially offset the effect of negative externalities on the environment, such as the opening of high-speed rail links and green travel options for residents.

5.2. Mechanism Verification (Mediating Effect Model)

The results presented above indicated that digital finance has had a remarkable impact on haze reduction. However, we ponder: What is the transmission mechanism through which digital finance affects haze pollution? This section considers the mediating effect of digital finance on haze pollution through technological innovation (*te*). The results in Table 3 indicated that the impact coefficient was 0.002, and there was a positive significant correlation with technological innovation, which means that the development of digital finance can promote the level of technological innovation. One critical reason was that digital finance has enabled enterprises to obtain capital inputs in a prompt and effective manner, and the efficiency of resource allocation within enterprises has subsequently been improved. When $PM_{2.5}$ was used as the explanatory variable, it indicated that the increases in digital finance and technological innovation both had a significant (at the 1% level) negative effect on haze pollution, with coefficients of elasticity of −0.037 and −0.092, respectively. There were double effects, including direct and indirect. On the positive side, the effect of digital finance on technological innovation has further improved $PM_{2.5}$ pollution control measures. Combined with comprehensive regression results, the intermediary effect was found to be significant. Digital finance will increase the level of technological development, which will have an effect on environmental pollution. Consequently, there is an intermediary mechanism by which digital finance plays a "clean" role through technological innovation.

Table 3. Results of the mechanism verification analysis.

Variables	(1) *lnpm*	(2) te	(3) lnpm
$lnifi$	−0.037 *** (0.013)	0.002 *** (0.000)	−0.231 *** (0.020)
Te			−0.001 *** (0.000)
$Constant$	15.143 *** (1.676)	4.755 *** (0.012)	1.304 (2.217)
Control variables	YES	YES	YES
$Fixed\ Effect$	YES	YES	YES
$R-squared$	0.462	0.034	0.521

Note:***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

5.3. Result of the Threshold Effect Model

We examined the panel threshold effects with two threshold variables (digital finance and technological innovation) on the environmental indicator ($PM_{2.5}$) in order to determine whether there is a nonlinear relationship between digital finance, technological innovation, and $PM_{2.5}$, with asymmetric upper and lower boundaries. Two models were applied to achieve this. Digital finance and technological innovation were used as threshold variables. Both of them were at a significant level in the regression relationship.

Table 4 indicates the panel threshold results. For model 1, applying digital finance as the threshold variable, $q_1$and q_2 split digital finance into three different phases: high-level digital finance (above 5.16), mid-level digital finance (between 4.724 and 5.16), and low-level digital finance (below 4.724). The results showed that digital finance was negatively correlated with haze pollution across the entire stage with the highest coefficient in the high-level phase (−0.095) and the lowest coefficient in the mid-level phase (−0.093). This result indicated that digital finance was the critical force for reducing haze pollution in China, and digital finance affected haze pollution dynamically.

Table 4. The panel threshold effect model results.

Variables	(1) *lnifi*	(2) *te*
$lnifi \cdot \mathrm{I}(\mathrm{Th} < \mathrm{q}_1)$	−0.093 ***	−0.001
	(0.016)	(0.014)
$lnifi \cdot \mathrm{I}(\mathrm{q}_1 \leq \mathrm{Th} \leq \mathrm{q}_2)$	−0.079 ***	−0.019
	(0.014)	(0.014)
$lnifi \cdot \mathrm{I}(\mathrm{Th} > \mathrm{q}_2)$	−0.095 ***	−0.030 **
	(0.014)	(0.013)
Control variables	YES	YES
R-squared	0.512	0.476

Note: ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

The threshold variable was technological innovation in the model 2, which was similar to model 1; technological innovation also had two thresholds and split technological innovation into different asymmetric phases: high-level technological innovation (above 19.663), mid-level technological innovation (between 19.435 and 19.663), and low-level technological innovation (below 19.435). The results showed that the high-level technological innovation phase had the most serious effect on haze pollution. By comparison, the other two phases were different; there was no remarkable negative correlation between technological innovation and haze pollution, implying that at the beginning stage technological innovation had little effect on haze pollution. Thus, the further promotion of technological innovation is necessary to reduce haze pollution.

5.4. Spatial Spillover Effect

5.4.1. Spatial Correlation Test

Considering the degree of haze pollution and the levels of digital finance across China, there were significant regional differences, and the Moran index was used to test the spatial correlation of haze pollution and digital finance under a geographical matrix. The formula for the Moran's I is as follows:

$$Moran\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{11}$$

where $S^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2$, $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, and x and w_{ij} are the observed and matrix values, respectively.

As seen in Table 5, the global Moran's I values for the analysis of haze pollution as well as digital finance were significantly positive in 2011–2016 in China. Thus, both of them had significant spatial autocorrelation and spatial clustering phenomena in the relationship between haze pollution and digital finance in China. To explain this spatial correlation more intuitively, local indicator of spatial association (LISA) scatter plots of haze pollution in 284 cities in 2011 and 2016 were constructed. Figure 3 shows that the trend of haze pollution in China was narrowing and had notable local spatial agglomeration characteristics.

Table 5. Results of the global spatial autocorrelation test.

Year	(1) ln*PM*		(2) ln*ifi*	
	Moran's I	**Z value**	**Moran's I**	**Z value**
2011	0.163 ***	18.514	0.064 ***	7.434
2012	0.196 ***	22.128	0.079 ***	9.108
2013	0.14 ***	15.976	0.098 ***	11.239
2014	0.056 ***	6.623	0.049 ***	5.861
2015	0.068 ***	7.929	0.076 ***	8.769
2016	0.11 ***	12.633	0.088 ***	10.185

Note: ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

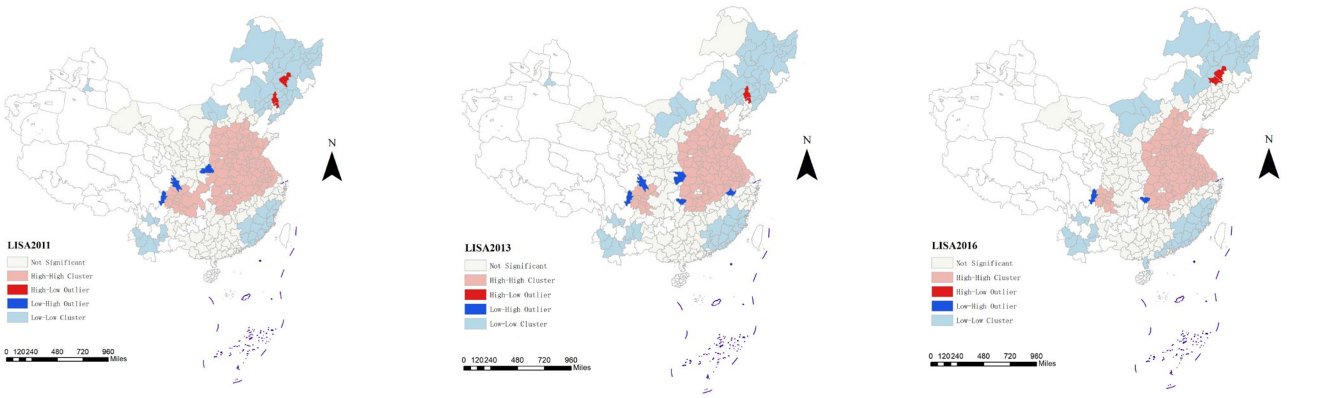

Figure 3. LISA scatter plots of haze pollution.

5.4.2. Estimation of the Spatial Spillover Effect

The national results from the dynamic SDM under the space-and-time fixed effect are shown in Table 6. In the regression results, the coefficient of the time lag term of haze pollution was significantly negative, which verified that haze pollution changes have time- and path-dependent characteristics. The spatial correlation coefficient ρ was significantly positive with the coefficient of 1.106, signifying that local haze pollution had a significant interregional interaction, i.e., there was a spatial spillover effect that influenced haze pollution. An increase in pollution emissions in a specific region will harm the natural environmental of adjacent areas.

With respect to the coefficient of lnifi, which was significantly negative at −0.529, we assumed it to be related the inter-city technology innovation effect. The spatial effects of digital finance showed no differences when compared with the existing regression results. The coefficient of w* lnifi was positive at the 1% significance level, signifying that the levels of digital finance in neighboring cities and the local haze pollution have a positive correlation.

This may be caused by expanding the local production scale in response to the government competition from surrounding cities.

Table 6. Spatial panel model regression results.

Variables	(1) EWM	(2) EDSWM	(3) GWM
$L.lnpm$	−0.240 ***	−1.371 ***	−0.815 ***
	(0.052)	(0.065)	(0.044)
$L.wlnpm$	1.609 ***	2.521 ***	8.957 ***
	(0.090)	(0.091)	(0.098)
$lnifi$	−0.529 ***	−1.807 ***	−1.404 ***
	(0.053)	(0.108)	(0.062)
Control	YES	YES	YES
$Wlnifi$	2.103 ***	3.160 ***	9.448 ***
	(0.135)	(0.195)	(0.337)
ρ	1.106 ***	1.147 ***	1.782 ***
	(0.002)	(0.001)	(0.005)
σ^2	0.003 ***	0.001 ***	0.004 ***
	(0.000)	(0.000)	(0.000)
R^2	0.138	0.171	0.001

EWM, DSWM, GWM refer to economic weight matrix, distance spatial weight matrix, and geographical weight matrix, respectively. ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

5.4.3. The Decomposition of the Spatial Spillover Effect

Based on previous studies, we adopted the spatial regression model partial differential method to show the spatial spillover effects of variables more accurately and avoid estimation bias in the regression results and to further decompose the correlation of digital finance and haze pollution into direct, indirect, and total effects. Because the dynamic spatial model was adopted in this study, both the direct and indirect effects needed to be decomposed into long- and short-term effects, respectively. The direct effects reflect the impact of local digital finance on local haze pollution; the indirect effect represents the influence of digital finance in neighboring areas on local haze pollution; and the total effect represents the overall impact of digital finance on haze pollution. The specific regression results under the economic weight matrix, geographical weight matrix, and economic distance spatial weight matrix are shown in Table 7. Two preliminary conclusions were drawn. First, in both the short- or long-term, the coefficients of the main independent variable stayed the same in sign and significance with elasticity coefficients of −0.578, −14.331, −0.437, and −0.573, respectively, which demonstrated that digital finance could mitigate haze pollution steadily in both the local and adjacent areas. Furthermore, the coefficients of digital finance in the short-term were higher than the corresponding coefficients in the long-term. This did not support a cyclic cumulative effect.

Table 7. The regression results for six different effects.

Variables	(1) EWM	(2) EDSWM	(3) GWM
Short Direct Effect	−0.578 ***	−0.457 ***	−1.740 ***
	(0.051)	(0.081)	(0.062)
Short Indirect Effect	−14.331 **	−8.711 ***	−8.569 ***
	(1.220)	(0.626)	(0.435)
Short Total Effect	−14.908 ***	−9.168 ***	−10.309 ***
	(1.223)	(0.610)	(0.446)
Long Direct effect	−0.437 ***	−0.573 ***	−1.071 ***
	(0.040)	(0.044)	(0.087)
Long Indirect effect	−0.573 ***	−0.466 ***	−0.149 **
	(0.044)	(0.069)	(0.059)
Long Total effect	−1.071 ***	−1.039 ***	−0.904 ***
	(0.087)	(0.069)	(0.039)

Note: ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

5.5. Heterogeneity Analysis

We found a remarkable correction between digital finance and haze pollution through the above research. However, the situation in local space may be atypical and completely different from the situation in overall space. Specifically, the territory is vast in China, and even within the country the degrees of digital finance and haze pollution display great differences. Therefore, the impacts of digital finance on haze pollution may be very distinct among different regions. According to the Ecological Environment Bulletin in 2017, among the 74 cities in the first stage of the implementation of the new air quality standard, the 10 cities with the poorest air quality were mainly concentrated in the north. Northern cities are generally more vulnerable to haze weather. As a result, this study placed an emphasis on southern and northern areas. There may be prominent differences in economic development mechanisms and the industrial structure among prefectures as a result of their different resource endowments. Prefectures were therefore divided into two parts, including resource-based (RB) and non-RB categories when obtaining prefectures listed as RB from the list of RB cities in the "Notice of the State Council on Issuing the Sustainable Development Plan for the Resource-based Cities of the Whole Country (2013–2020)."

The regression results are shown in Table 8. The specific conclusions were as follows. First, the coefficient of *lnifi* was in line with the basic regression (with coefficients of elasticity of −0.044, −0.065, −0.047, and −0.020); however, the contribution of digital finance to haze pollution reduction in non-RB prefectures was insignificant. Second, although the existing regional heterogeneity was recognized, the elasticity coefficient of *lnifi* in southern regions was −0.06, which was much higher than in northern regions. This may be because the remarkable economic development level and technological advantages of the southern and RB regions of China have been conducive to the development of digital finance, forming "post-advantage" conditions relative to the northern and non-RB areas. Not surprisingly, regions where digital finance was more highly developed were better able to mitigate haze pollution. Therefore, strengthening the coordination of digital finance and haze pollution in all regions is necessary.

Table 8. The results of the heterogeneity analysis.

Variables	(1) Northern Regions	(2) Southern Regions	(3) RB	(4) Non-RB
$lnifi$	−0.044 *	−0.065 ***	−0.047 **	−0.020
	(0.023)	(0.016)	(0.023)	(0.017)
R-squared	0.228	0.714	0.382	0.532
Control variables	YES	YES	YES	YES
Fixed Effect	YES	YES	YES	YES

Note: ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

5.6. Robustness Test

Four methods were applied to prove the robustness of the research results: (1) Replacing the core explanatory variables. Specifically, *ifi/100*, the coverage breadth of digital finance, the depth of using digital finance, as well as the digital support services were substituted as the core independent variables. The regression results were consistent with the baseline scenario and were remarkable at the 1% level (see column 1 of Table 9). (2) Shortening the sample time. We adjusted the study period to 2012–2016, and the results showed that digital finance could reduce haze pollution significantly (see column 2 of Table 9). (3) Excluding municipality samples. We only retained prefecture-level cities as samples for the regression, omitting municipalities, and the results were the same as the baseline regression results (see column 3 of Table 9). (4) The instrumental variable (IV) method. We eliminated the endogenous influences by employing the IV method. The number of information transmission computer services and software practitioners was used to build the instrumental variable (IV). Qualified IVs are supposed to satisfy the two conditions of correlation and exogenous variables: (1) Correlation. Computer service providers and software practitioners enable digital finance to be realized. The more employees there are in these businesses, the more favorable conditions there are for the growth of digital finance. (2) Exogenous variables. The number of information transmission computer services and software practitioners was selected as an exogenous variable without affecting haze pollution directly. Additionally, the method also passed the Hansen's J test, and it was therefore appropriate to adopt the number of information transmission computer services and software practitioners as the IV of digital finance. The impact of the coefficient of lnifi on haze pollution was still significantly negative, which reflected the conclusions of the previous three methods.

Table 9. The robustness test.

Variables	(1) Repace the Core Explanatory Variales of Municipalities	(2) Exclude the Sample	(3) Shorten Sample Time	(4) IV
$ifi/100$	−0.091 *** (0.015)			
$ifi1$	−0.001 *** (0.000)			
$ifi2$	−0.001 *** (0.000)			
$ifi3$	−0.001 *** (0.000)			
$lnifi$		−0.036 *** (0.013)	−0.411 *** (0.032)	−0.152 ** (0.076)
R-squared	0.474	0.463	0.514	0.771
CV	YES	YES	YES	YES

Note: ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

5.7. Further Discussion

The development of digital finance will be affected by many factors, such as resource distribution, market scale, opening-up level, and so on, which in turn will profoundly affect environmental pollution. To estimate whether the development of digital finance steadily promoted haze reduction, the "Broadband China" policy was considered as an exogenous shock. The policy was formulated at a critical point in China's digital era, which further encouraged the growth of digital finance. The expansion of the "Broadband China" policy therefore provided the conditions for a good quasi-natural experiment.

As a well-known principle in spatial econometrics, we considered cities to be correlative. This facilitated the propagation of the effects of "Broadband China" from the cities in which the policy was implemented to the surrounding cities. We used a dynamic DID model to analyze the "policy effect." In order to adopt this method, constructing du and dt to represent a grouping variable and a time dummy variable, respectively, was a necessary step. The data range was the period of 2011 to 2016. Since 2013, the policy has gradually been implemented in certain Chinese cities. In this study, cities covered by the policy from 2013 to 2016 were regarded as the treatment group, and cities without the policy from 2013 to 2016 were regarded as the corresponding part—the control group. If they were part of the treatment group, du = 1; if not, du = 0. In addition, when supposing a city conducted the policy in a certain year, then dt = 1; on the contrary, dt = 0. On the basis of the SDID method, we focused on the interaction term du*dt (DID), which was described as the "policy treatment effect" of digital finance. Therefore, we specified the following estimation function:

$$\begin{aligned} \ln pm = & \sum_{i=1}^{n} \rho_{sdm}(w \ln pm + \gamma_0 + \sum_{i=1}^{n} x_i \lambda_i) + DID_{it}\lambda_i + WDID_{it}\lambda_i + \\ & \mathrm{w} \sum_{i=1}^{n} X_i \gamma_i + z_t + year_i + \varepsilon_{it} \end{aligned} \quad (12)$$

where du*dt is used to represent DID.X; *w*, *e*, and *r* represent a series of control variables, the economic weight matrix, the error term, and the parameter to be estimated, respectively. In addition, we controlled for the regional fixed effect and the time fixed effect to improve the robustness as represented by *z* and *year*, respectively.

Table 10 shows the regression results. The coefficients of DID in columns 1–3 were significantly positive (coefficients of elasticity of −0.080, −0.324, and −0.056, respectively), with little difference in the significance level and magnitude. This indicated that the policy effectively reduced haze pollution. The spatial correlation coefficient WX was significantly positive at the 1% significance level, with coefficients of elasticity of 0.187, 0.722, and 0.132, respectively, suggesting that policy implementation had a considerable interregional interaction.

Table 10. The baseline regression results of the SDID method.

Variables	(1) EWM	(2) DSWM	(3) GWM
did	−0.080 *** (0.022)	−0.324 *** (0.043)	−0.056 ** (0.028)
wx	0.187 *** (0.045)	0.722 *** (0.096)	0.132 ** (0.060)
ρ	0.990 *** (0.001)	0.948 *** (0.041)	1.134 *** (0.006)
σ^2	0.001 *** (0.000)	0.006 *** (0.001)	0.001 *** (0.000)
City fixed	YES	NO	YES
Time fixed	NO	YES	YES

Note: ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively.

6. Conclusions and Policy Recommendations

6.1. Conclusions

Haze pollution is a severe issue that holds back the pace of the green economic development, and most studies lack attention to the influence of digital finance on haze pollution. This study applied FE and RE models, a mediating effect model, a threshold panel model, and a dynamic SDM to test the effect of digital finance on haze pollution. We reached the following conclusions. (1) Digital finance significantly improved haze pollution control, and this conclusion was robust. (2) The mechanism analysis showed that technological innovation is an important channel for digital finance to mitigate haze pollution. (3) There was a nonlinear relationship between the effect of digital finance and haze pollution. (4) Haze pollution displayed a significantly positive spatial agglomeration in China. Digital finance can reduce local haze pollution but will aggravate haze pollution in adjacent areas.

6.2. Policy Recommendations

From the above conclusions, we offer the following policy recommendations.

(1) Digital finance is not only a considerable part of the economy, but it also gives "positive power" to the mitigation of haze pollution. A "national big data" strategy is now implemented and popularized in some cities. Therefore, it is essential to strengthen the construction of digital finance as well as accelerate the full coverage of digital finance throughout the country, making full use of the "national big data" strategy to reform backward industries and speed up technical innovation with cloud computing and small manufacturing. This will affect the intelligent infiltration, the development of information technology and ICT services, and subsequently influence productive power and green development.

(2) Policy makers should build a harmonious and ordered digital financial system and, in the meantime, break the blocks of haze control between regions. The relationship between haze pollution and digital finance exerts a significant spatial spillover effect, and uncoordinated development and invalid management issues can influence

the effectiveness of haze control. To form the foundation of a harmonious and ordered digital financial system, it will be to our advantage to promote the dynamic coordination of economic development, resource conservation, and environmental protection. Meanwhile, this may accelerate environment-friendly resource sharing between cities. There is a need to acknowledge the timeliness of digital finance's effect on haze pollution and strengthen the haze reduction effect of digital finance as far as possible.

(3) We must enhance the intermediary role of technological innovation, which is an important way for digital finance to reduce haze pollution. Therefore, the government should strengthen technological innovation investment, improve relevant legal measures, and encourage enterprises to take the path of innovation and development, which cannot ignore the need for an innovation linkage mechanism between cities and must give full play to the intermediary mechanism of technological innovation. In addition, because of the nonlinear effect of technological innovation on haze pollution, we should ensure that it breaks through the threshold as soon as possible.

(4) Considering the heterogeneity of digital finance and haze pollution, a dynamic and differentiated digital economy strategy should be implemented to make digital finance a "hardware" technical support for reducing haze in various regions, and the authorities should implement policies and measures according to local conditions. Specifically, relevant policies and measures should be appropriately tailored to the northern and non-RB cities to strengthen the digital finance coverage of those cities and promote the effective role of digital finance in the environment. At the same time, considering the spatial spillover effect of digital finance and haze pollution, it is necessary to implement dynamic linkage digital finance construction and haze reduction measures.

6.3. Limitations and Prospects

Although this paper analyzed the intermediary mechanism of digital finance affecting haze pollution, because of the limitations on research data, research methods, and other factors, there remain deficiencies and needs to be improved in the future. They are mainly reflected in the following three aspects:

(1) Limited by the data published in official statistics and considering the development speed of digital finance, this paper only selected 2011–2016 as the sample period, which can only be used for short-term analysis. At the same time, it took 248 cities in China as the research object, and the research perspective lacked microcosmic elements. With the continuous promotion of digital finance, micro subjects such as enterprise level also play a role that cannot be ignored. If we explore digital finance in the future, the research will be more in-depth and specific.

(2) Lack of a transmission mechanism test. In the theoretical analysis, this paper summarized in detail the impacts of digital finance on technological innovation and on haze pollution. However, in the empirical analysis, some transmission mechanisms were not tested by the econometric model, so the theoretical analysis and empirical test did not agree on all results. With more perfect data in the future, researchers should consider the mechanism test, realize the parallel between theoretical analysis and empirical analysis, and explore more targeted haze reduction measures.

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